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Numerical Modeling of the Seismic Behavior of Pile Group in Soil Slopes

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ABSTRACT: During past earthquakes many structures supported on pile foundations failed due to damage of pile, so the seismic behavior of pile group is interested by researchers. The behavior of these piles will be complicated when they were located in soil slopes. In this paper seismic behavior of pile group in soil slopes was studied via finite element method by the using finite element software ABAQUS program. For reaching this aim, effective parameters in seismic behavior of piles groups in soil slopes like as angle of soil slope, number and configuration of piles and the space of pile to diameter are selected. Numerical models are simulated in software and the properties of soil and piles are applied them. Computational simulations are adopted to consider the effects of pile spacing, diameter, and the configuration of pile groups and the variation of angle of soil slopes. Based on computational results, some charts with suitable combined parameters were presented (e.g. moment and displacement of piles) which declare that the behavior of pile group subjected to cyclic lateral loading is dependent to number, diameter, spacing, and location of piles in the group. Also it is demonstrated that the behavior of pile group is affected by slope angle.

1 INTRODUCTION

Deep foundations are widely used in civil engineering to provide the performance required by all types of structure .Catastrophic damage of some recent earthquakes such as North Ridg (1994),Kocaeli (1999),Chi (1999) and Bhuj(2001) have raised concern about the proper seismic design of the pile supported structure. The remedial works needed for damage piles can be very costly, thus seismic behaviour of pile group and mechanism for damages need to be further studied.

Most of the studies reported in literature have been performed that are built on flat lands. Novak (1974) has used subgrade reaction approach to deal with pile foundation including the groups. Kuhle-meyer (1979 a, b) applied finite element techniques for dynamically excited single piles. Kaynia and Kausel (1982) have analyzed piles and piles group in a layer half space using Green` function formulation. Wu & Finn (1997) have done a time domain non-linear Quasi three dimensional analysis for single piles and piles groups. Lianapatheriana & Poulos (2005) have modeled soil-pile interaction for a dynamically loaded beam on Winkler foundation.

Also many studies have been done to consider the effect of soil movement on piles. These include piles in near in or near an embankment built, bridge abutment piles, piles adjacent to an excavation and piles in unstable that are called passive piles. For lateral soil movement in embankment, Tschebotorioff(1973) suggest that the pile will be subjected to a triangular distribution of earth pressure due to soil movements arising from the embankments loading.

Poulos and Davis (1980) provide a conservative value for the uniform lateral pressure based on the undrainged shear strength of clay layer. Stabilizing piles in slopes are known as shear piles. Shear piles are reinforced concrete piles that pass through the unstable layer and anchored at their lower end at stable soil or bedrock. Design of the reinforcement steel is controlled by the maximum bending moment developed in the pile. The impact of excavation on exciting adjacent piles has been investigated by Chen and Poulos (1996) and designed charts of supported and unsupported excavation are provided.

By studying the literature, it was observed that the most studies are performed for the seismic behavior of piles and pile groups, however till now no studies have been done on the seismic behavior of piles groups in slopes.

2 NUMERICAL MODELING

2.1 FINITE ELEMENT MODELING

Three-dimensional models are used to present the soil-pile systems. Finite element has been developed for the system. Due to the aim of this study, full of the actual model was built in finite element software ABAQUS.

The three-dimensional finite element meshes (Figure 1) comprise two parts: the concrete pile groups and the soil. Interface elements that are capable of simulating the frictional interaction between the piles and the soil are used. Since there is no water in the system, the excess pore water pressure is zero in this finite element analysis. The piles are assumed to be in perfect contact with the soil at the start. Interaction between the pile and the soil is simulated using penalty type interface element between the piles and the soil, also in order to obtain more real result in analysis and avoiding reflect of waves from side boundaries into the model, infinite elements were used.

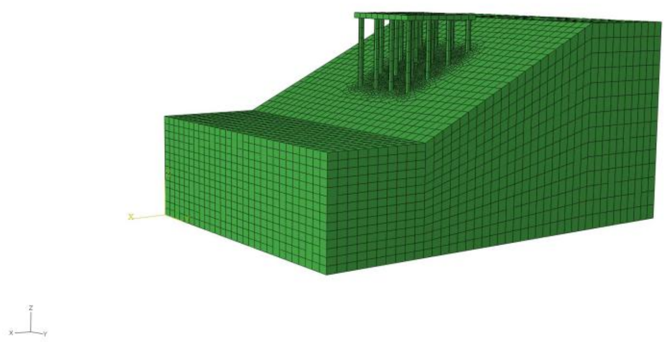

Figure1. Finite element full model

2.2 MODEL PROPERTIES

Regarding the main purpose of these parametric studies, the properties of the analyzed models and the several of parameters were adjusted so that the effects of following parameters are considered (Figure2):

- Angle of soil slope(tanα)
- Configuration and number of piles in group (r×c)
- Space of piles to pile diameter(s/d)

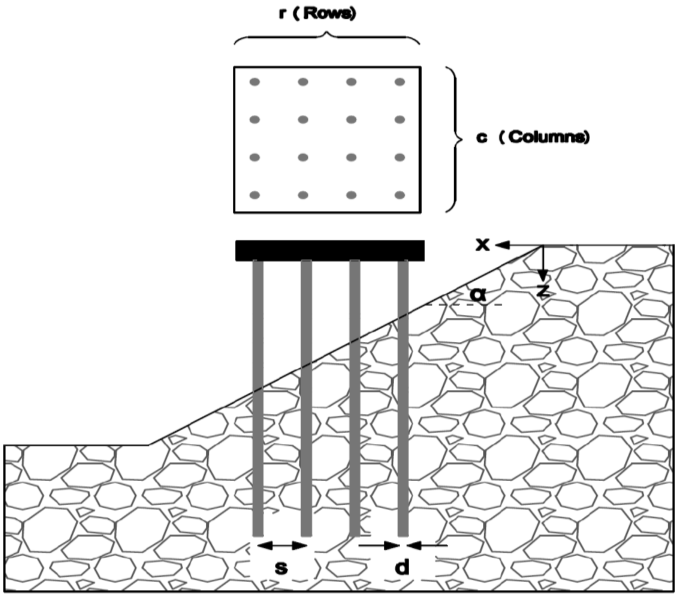

Figure2: The selected parameters for parametric study

Table 1 shows the assumed various value of every one of this parameters.Also Table 2 shows some detailed parameters that are connected to pile and soil properties. Time history of acceleration of El Centro (1940) earthquake is considered as the ground surface motion in these analyses. Time history of this motion is shown in Figure 3.

Table1: The selected parameters for parametric study

Pile Group			Slope
Group Configuration		s/d	tanα
Single pile	1*1	3	0
Square groups	2*2	5	1:2
	3*3	7	1:1.5
	4*4	10	1:1.2

Table 2: The properties of pile and soil

case	Parameter	Value	Unit
Soil	E	25	MPa
	VS	200	m/s
	μ	0.3	-
	γ	18	KN/m³
	C	18	Kpa
	Φ	24	Deg
pile	E	2.00E+07	Kpa
	Diameter	0.5	m
	Length	15	m
	I	6.1e-03	m4

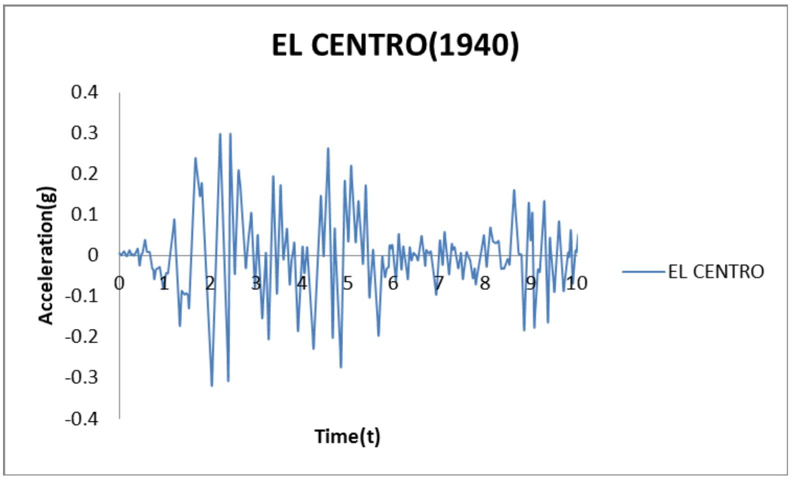

Figure3: Time history for El Centro (1940) earthquake

3 RESULTS AND DISCUSSION

3.1 THE EFFECT OF THE ANGLE OF SLOPE

According to Table 1, four different angles (tanα=0, tanα=1:2, tanα=1:1.5, and tanα=1:1.2) are considered for soil slope. The profiles of the ultimate deflection and bending moment of piles are shown in 4×4 square groups in Figure4 and 5. As shown in these Figures, increasing the angle of slope causes the change in distribution profile and the values deflections and moments of the piles in the group.

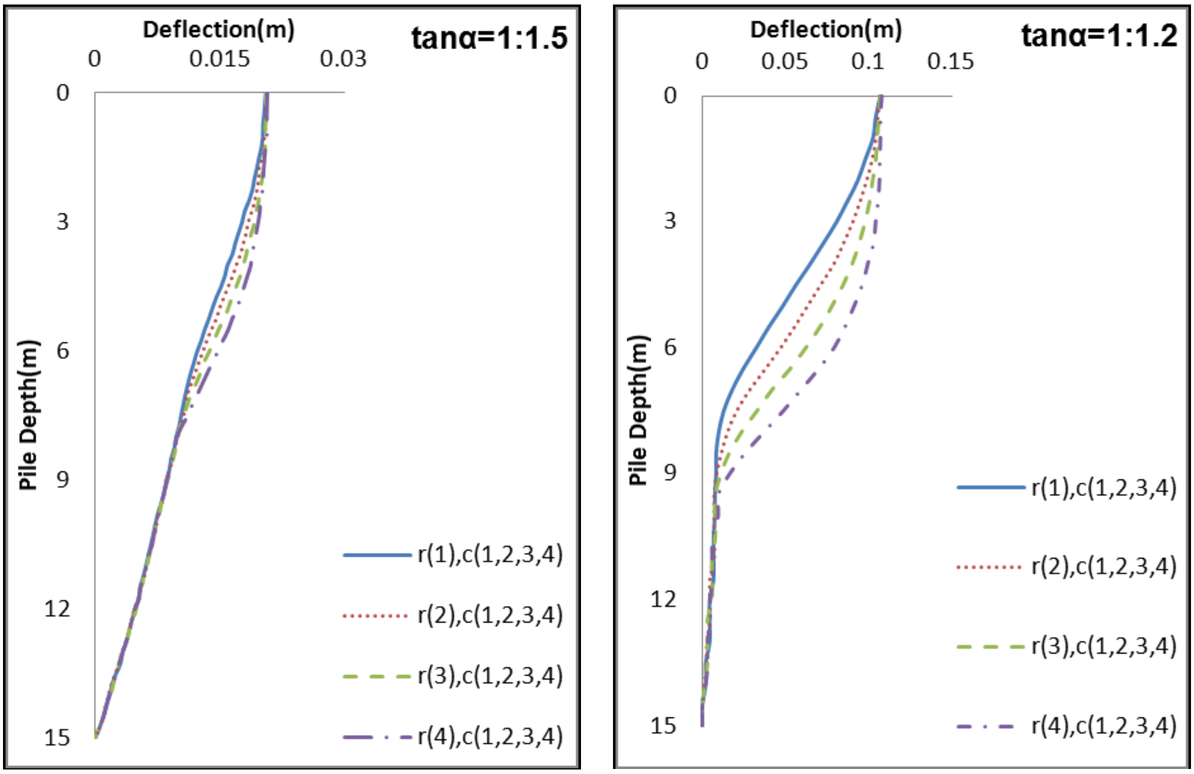

Figure4:The deflection of 4×4 pile groups in 2 different angles of slopes

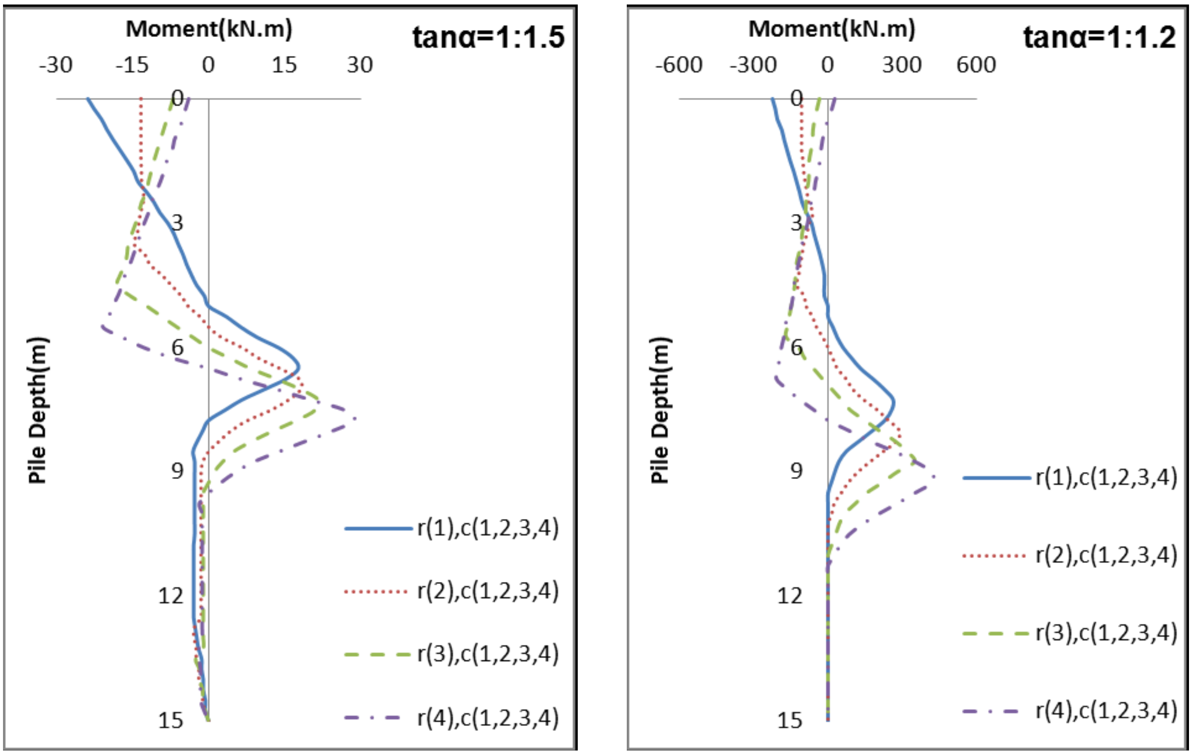

Figure5:The bending moment of 4×4 pile groups in 2 different angles of slopes

Increasing the angle of slope causes the more difference in free length of different piles in the group and decreasing in interruption acceleration. These two direct results on one hand cause the increasing in deflections and moments values and on the other hand increase the difference of mentioned values in different piles of a particular group. (Figure 6)

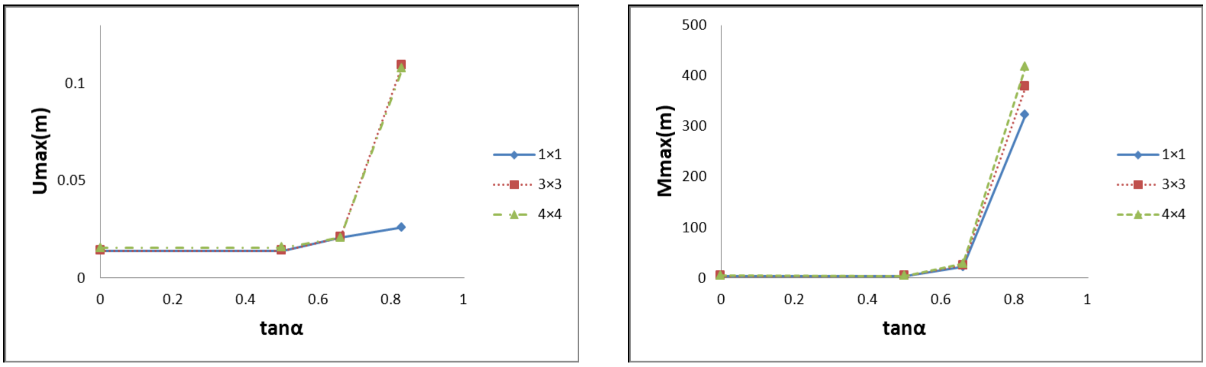

Figure6: Effect of angle of soil slope on the deflection and moment of piles in n×n square group

It is necessary to notice that for each particular case, there is a threshold angle that for larger slopes the angle of ground's surface and the behavior of group reveal. Evidently, the threshold angle may be dependent on mechanical specifications of the soil.

3.2 THE EFFECT OF PILES CONFIGURATION IN GROUP

Just as it is shown in Table 1, piles configuration is considered in square groups. Figure 7 show the deflections and bending moments created in 3×3 square groups.

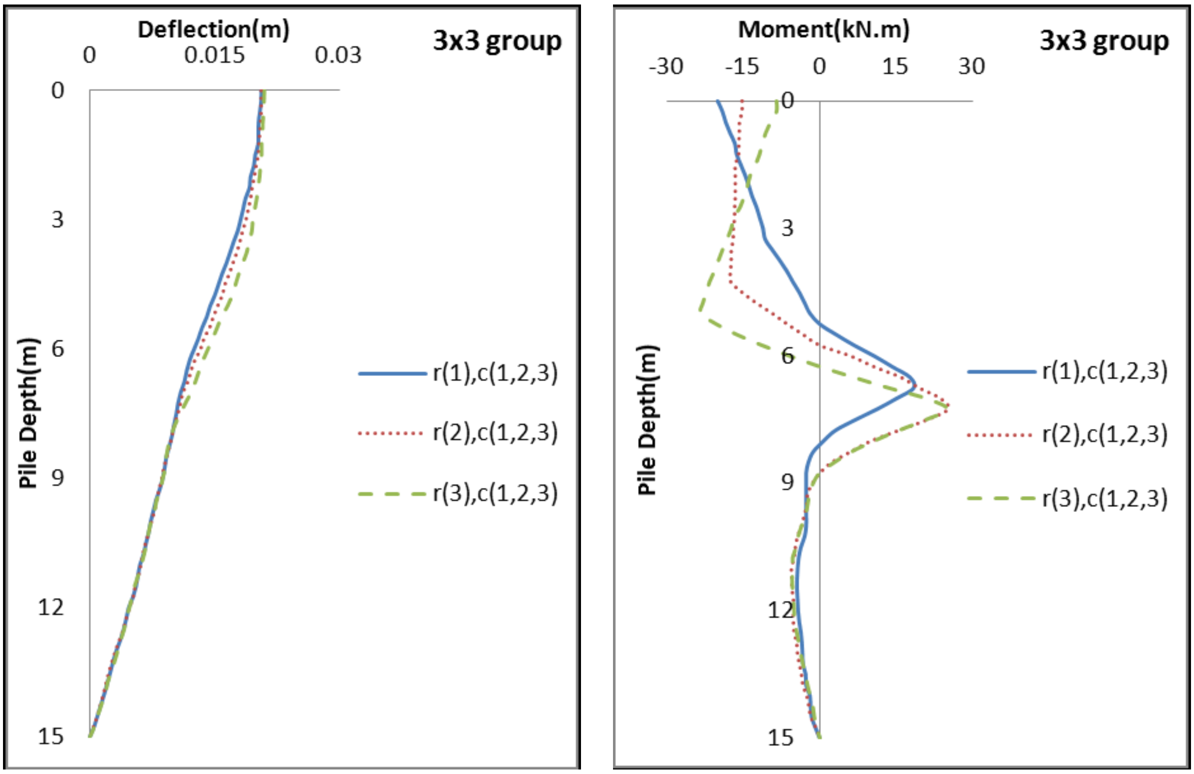

Figure7:The deflection and bending moment of 3×3 group

As noticed in Figure8, increasing the number of piles in a group causes maximum decrease in the place changing in the pile head and maximum in-crease in bending moment in the pile length; although we should notice that increasing the number of piles in group causes no increase in maximum bending moment created in all piles.

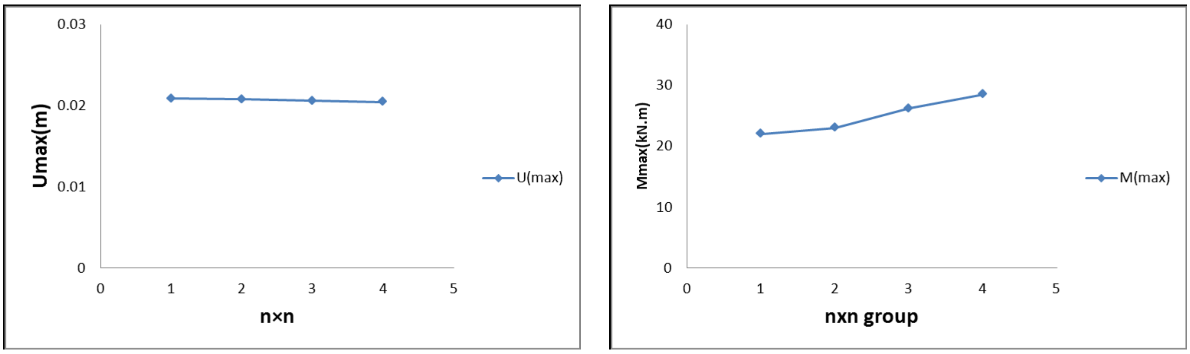

Figure8: The maximum value of deflection and moment developed on piles in n×n groups

3.3 THE EFFECT OF SPACE TO DIAMETER RATIO (S/D)

One of the most essential effective factors on the response of pile group is the ratio of the space to diameter of piles in group(s/d). Figures9 and 10 compare the profiles of the deflections and moments of group pile in particular group 4×4.

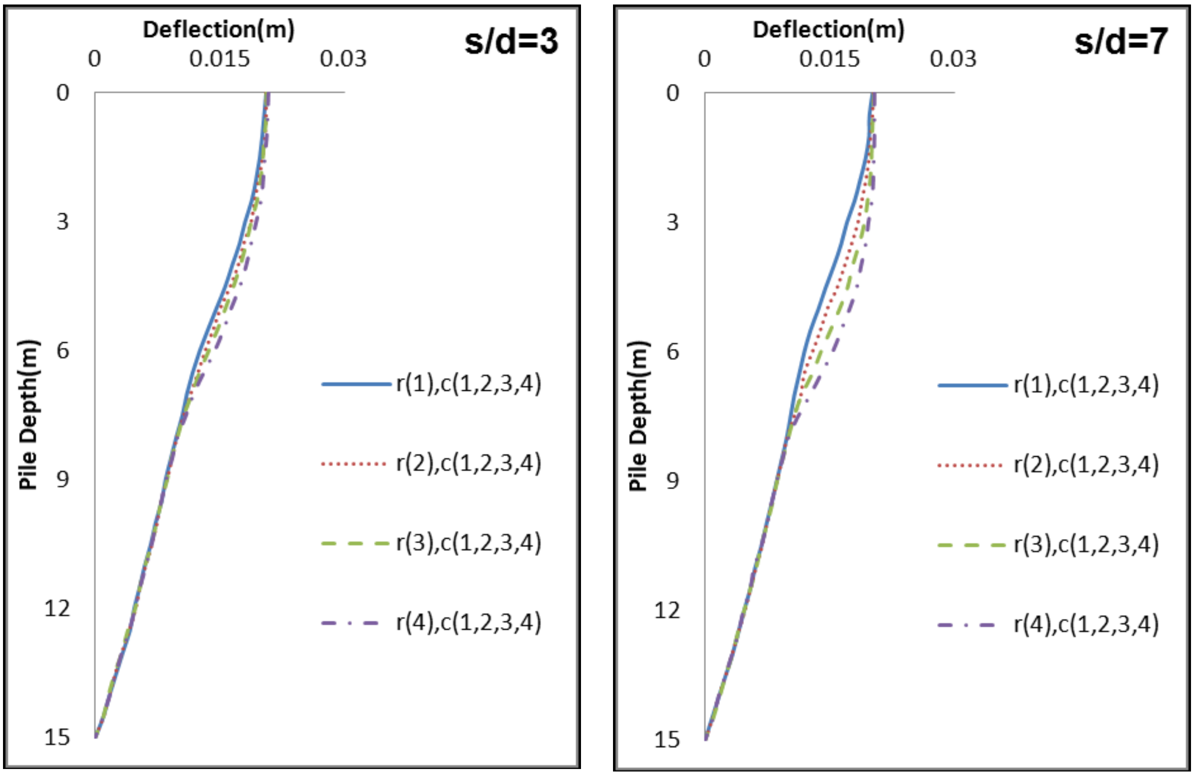

Figure9: Effect of s/d on the deflection of piles in 4×4 square group

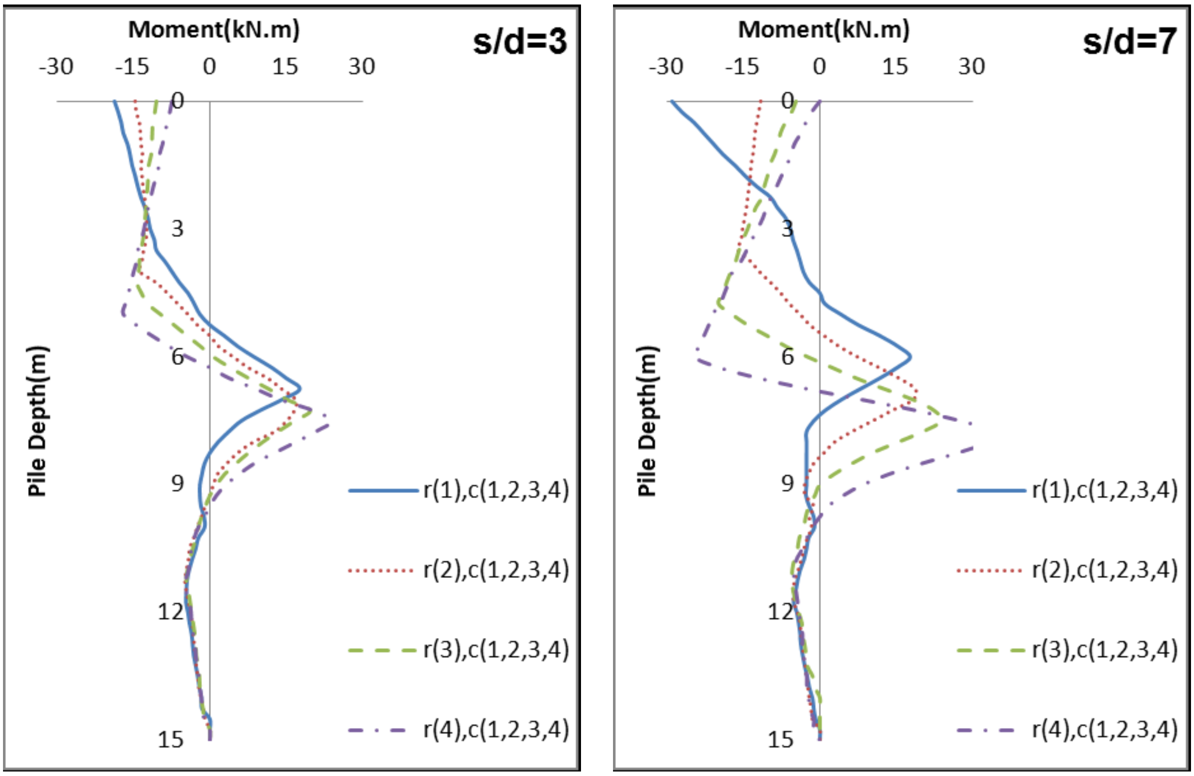

Figure10: Effect of s/d on the bending moment of piles in 4×4 square group

As shown in Figure 11, an increase in the ratio of s/d in a particular group causes an increase in the moment values and deformation in piles and also in-creasing their difference among piles of a group. The more number of piles in a group causes the more affectivity of s/d parameter.

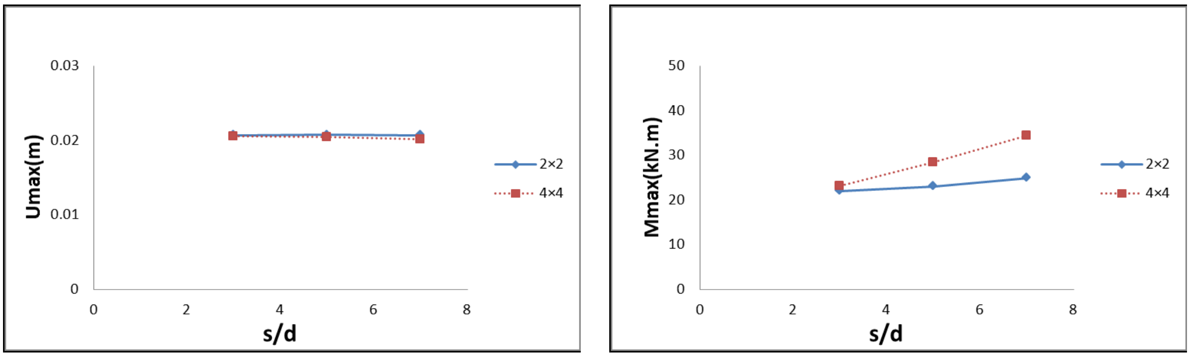

Figure11: Effect of s/d on the maximum value of deflection and moment developed on piles

4 CONCLUSIONS

A three-dimensional finite element analysis performed to investigate the behaviour of pile group in soil slope effects from seismic loading. Following conclusions can be drawn from this study:

- Increasing the number of piles in a group causes maximum decrease in the place changing in the pile head and maximum increase in bending moment in the pile length
- Increasing the number of piles in group causes no increase in maximum bending moment created in all piles.
- Increasing the angle cause the increasing in deflections and moments values and the difference of mentioned values in different piles of a particular group.
- Increase in the ratio of s/d in a particular group causes an increase in the moment values and deflections in piles and also increasing their difference among piles of a group.

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